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Wireless Technology for Command Control and Communications

by

C. H. Lee

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Naval Postgraduate School
Monterey, California 93943-5000

Rear Admiral T. A. Mercer
Superintendent

H. Shull
Provost

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13. ABSTRACT *(Maximum 200 words)*

There are many different views on exactly what is PCS. But, the majority agree that "integrated access," "personalized identification," and "mobile roaming" are the themes of PCS. Personalized services means that identification is not based on a terminal but instead on a person. PCS will use digital technology, standard procedures, and air interface for universal roaming. This means a tetherless connection through all the infrastructure for voice, data, image, and video services. The intensive development can be divided into the following four areas: Digital cellular or digital PCS, wireless data network services (WWAN, WLAN, WPBX), land mobile radio (LMR), and mobile satellite services (MSS). These areas characterize wireless technology in their own perspectives, possible DOD applications will be discussed in this report.

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WIRELESS TECHNOLOGY FOR COMMAND CONTROL AND COMMUNICATIONS

A STUDY REPORT

C. H. Lee, code Ec/Le
Navla Postgraduate School
Monterey, Ca. 93943
email: chlee@ece.nps.navy.mi;
408-656-2190, fax 408-656-2760

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Fueling the Mobile Telecommunication Evolution:

In 1986 the FCC issued the "Code of Federal Regulation", Part 22, that specified the foundation of the Advanced Mobile Phone Services (AMPS). Basically, 20 MHz around 880 MHz and 20 MHz around 835 MHz are taken out from military UFH bands to the civilian world. In less than a decade this created the most dynamic and most profitable telecommunications cellular phone industry. Table I shows the accumulated subscribers over the years. Worldwide users grew from 4.2 million in 1988 to 23.7 million in 1992. Projected growth will be 57.8 million at the end of 1996. Foreign growth in developing countries is even more dramatic than the domestic market due to the lack of existing communication infrastructure. This also created a large job market where US. expertise and technology can be employed.

	1988	1992	1996
US.	2 M	11.7 M	30 M
Western Europe	1.6 M	7 M	13.8 M
Rest of the World	0.6 M	5 M	14 M
TOTAL	4.2 M	23.7 M	57.8 M

Table I: Worldwide Cellular Communication Subscribers, after T. Schultz, Motorola [2]

The political sentiment in Congress is going toward repeating this success story of creating new industry and creating more jobs. In 1993, 40 MHz for unlicensed use and 120 MHz for licensed use around 1800 MHz are ruled by FCC for Personal Communication Services (PCS) development. The FCC defines PCS as:

> "a family of mobile or portable radio communication services which could provide services to individual or business and be integrated into a variety of competing networks. . . . The primary focus of PCS will be to meet communication requirements of people on the move" [1].

Details of this FCC allocation will be described in later sections. The National Telecommunications and Information Administration (NTIA) is studying the release of additional 100 MHz for future growth of mobile services in the next 10 years [3]. The implication is important to DoD users and military services because there could be possible spectrum conflict and shared use in the future.

Pillars of Personal Communication Services (PCS):

As mentioned in FCC's definition of PCS, it refers to integrated services to people on the move. There are many different views on exactly what is PCS. But, the majority agree that "integrated access," "personalized identification," and "mobile roaming" are the themes of PCS. Personalized services means that identification is not based on a terminal but instead on a person. In Europe telephone calls in GSM system are based on a personalized smart card (subscriber ID module, SIM) that can be inserted into any rented phone. Roaming of cellular phones was restricted to a country in old analog systems such as AMPS in the US. or TACS in Europe. PCS will use digital technology, standard procedures, and air interface for universal roaming. The access and control of infrastructure should be ubiquitous. This means a tetherless connection through all the infrastructure for voice, data, image, and video services. PCS will support intelligent integrated transparent access to the Public System of Telephone Networks (PSTN) and the Public System of Data Networks (PSDN). Obviously, interoperability and interworking will be the main task for communication carriers and PCS licensees.

Another characteristic that people associate with PCS is "DUITS". D stands for Digital, U stands for ubiquitous, I stands for Interoperable, T stands for Transparent, and S stands for Secure services. From the user point of view, transparent, ubiquitous service with security are really necessary attributes in PCS.

New technologies that can support this kind of service seems mature as well, which includes digital RF media multiple access, battery technology, high speed low power DSP chips, and ISDN infrastructure. By the end of 1994 half of the PSTN carriers will have upgraded their switches to handle ISDN services. Due to the rapid advance of portable personal computers (PCs) in the personal computer industry, low power processor chips and battery technology are prepared. Decades of development in satellite communication (SATCOM) have proven the success of digital multiple access technology. These are the foundations of the PCS development. Continuing technology improvement in these areas will be seen in the future. Some people generally referred to the important mobile development part of PCS, as an umbrella term, "wireless technology."

Areas of Wireless Technology:

The objective to monitor the development of wireless technology is to see the trend so that DoD can either spin-on new applications or countermeasure against new wireless technology. Generally, intensive development can be divided into the following four areas: Digital cellular or digital PCS, wireless data network services (WWAN, WLAN, WPBX), land mobile radio (LMR), and mobile satellite services (MSS). These areas characterize wireless technology in their own perspectives, which will be discussed in the following sections. In the recent climate of decreasing DoD expenditure, more interest is directed towards using commercial off the shelf (COTS) equipment. For tactical or special military usage, COTS may neither offer the full capability nor satisfy all requirements of the applications. The intention is to study the problem so that successful deployment of COTS in some DoD application is possible. Unique DoD issues or requirements will be discussed in the following section.

FCC PCS Spectrum Reallocation:

The FCC rules in 1993 on the PCS channel plan are in two categories. Table II shows the licensed PCS band. Table III shows the unlicensed PCS band [4]. To promote sharing of spectrum a "primary service" is differentiated from a "secondary service" that are allowed on non-interference basis. To foster competition among PCS providers of cellular operators, 51 Major Trading Area (MTA) and 492 Basic Trading Area (BTA) are set up for competitive bidding on 10-year terms. The licensee has a percent service requirement over a 10 year time period. In other words, if the spectrum is idling, the license can be terminated. As indicated,

Channel Block	Spectrum Provide (MHz)	Preferred Range (MHz)	Service Area	Eligi-bility
A	30	1850-1865/ 1930-1945	MTA	Open entry except cellular in market
B	30	1865-1880/ 1945-1960	MTA	Open entry except cellular in market
C	20	1880-1890/ 1960-1970	BTA	Proposed for preferred categories
D	10	2130-2135/ 2180-2185	BTA	Proposed for preferred categories
F	10	2135-2140/ 2185-2190	BTA	Open entry, with cellular in market
F	10	2140-2145/ 2190-2195	BTA	Open entry, with cellular in market
G	10	2145-2150/ 2195-2200	BTA	Open entry, with cellular in market

Table II: Licensed PCS Channel Plan

Frequency (MHz)	Transmission Mode
1890--1900	Voice (i.e., isochronous)
1900--1920	Data (i.e., asynchronous)
1920--1930	Voice (i.e., isochronous)

Table III: Unlicensed PCS Channel Plan

specific bands for MTA are reallocated for exclusive use on PCS services only. This is intended to stimulate new technology development. Block C and block D in Table II are set aside to provide special opportunity for small businesses, rural telephone, and minority/women businesses. This is a reallocation ruling. That means there are incumbent licensees operating in these bands already. A PCS licensee is required to protect or compensate incumbent fixed microwave operations generally in accordance with current industry standards.

In the band of 1890-1910 MHz there are 1400 incumbent licensees. In the band of 1910 t0 1930 there are 400 incumbents. FCC designates UTAM, Inc., to address the obstacle of deployment of unlicensed PCS. UTAM must submit a relocation funding plan to the Commission on Public Notice for comments. Nomadic devices are not permitted to be deployed until a band is cleared. Non-nomadic devices may be deployed early under coordination of UTAM for non-interference to incumbent microwave links. For unlicensed PCS, a Wireless Information Network Forum (WINFORUM) is created that involves greater than 30 computer, PBX, LAN software manufacturers. The early product is the document on "Spectrum Sharing Etiquette" [5] that establishes preliminary guidelines for sharing unlicensed PCS bands. Many activities related to this new FCC reallocation is going on now.

Digital Cellular Telephone Systems:

The cellular telephone market enjoyed successful growth over the years. In order to sustain the growth and increase market penetration, new digital cellular systems are favored. Current market penetration in the US. is about 4.5% of the population. Finland has the highest penetration of 7% in the world. The total cost in Finland, including equipment and service cost per subscriber, is only $700/yr. The US. cost is about $1,000/yr. In addition to lower per subscriber cost, digital system offers higher capacity than the analog system. If the equipment and operation costs for new digital systems is comparable to the old, the total cost per subscriber to provider can be dramatically reduced. The capacity increase for going into digital systems are expected in the range of 6 X to 15 X.

In Europe there are three existing analog systems, TACS (England), NMT (Scandinavia), and C450 (Germany). European countries being geographically near each other are acutely aware of the incompatible cellular systems. In 1982 Europe took the lead in planning and deployment of digital Global System for Mobiles (GSM). Currently, GSM has been adopted by 87 licensees in 51 countries including Europe, Australia, and Southeast Asia [6]. Because of early planning and adoption, it has the potential to be a widely used global system.

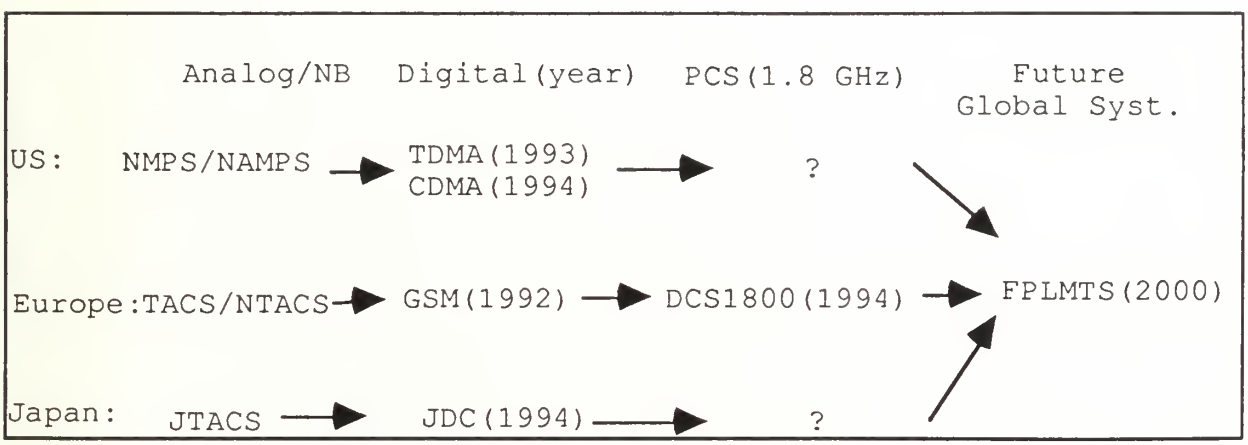

Figure 1. World wide Digital Cellular Development

Figure 1 shows a migration path of analog cellular to the digital system. Europe has GSM deployed in 1992. In order to increase capacity further at 900 MHz and operate it in metropolitan in micro cells GSM were modified and adopted in the Digital Cellular System at 1800 MHz (DCS1800) in England in 1994 [7]. This actually prompted the US. Congressional action on PCS reallocation discussed previously. Also shown in the figure, Japan is deploying digital systems as Japan Digital Cellular (JDC), and US is adopting IS-54. Time Division Multiple Access (TDMA), and IS-95, Code Division Multiple Access (CDMA). The dominant migration path to digital cellular in the US is not clear. Dual standards (TDMA/CDMA) are both under tests with TDMA deployed in Florida early. Apparently the US will allow the market to do the shakeup.

The ultimate goal for cellular phone is to have a unified system in the world. It is referred to as the Future Public Land Mobile Telecommunications System (FPLMTS). This will employ a common radio link interface at 2 GHz that can accommodate worldwide compatible operation. Details of this system are not conceived yet, and it is believed that this will occur beyond the year 2000. As you can see, the US. is currently planning and preparing for the PCS spectrum (1.8 -- 1.9 GHz). Generally, it is believed that the new PCS will provide higher capacity increases than the digital cellular. Due to necessary wired infrastructure to support PCS, it is believed that economically justifiable deployment of PCS will happen in high populated areas (> 400 K) initially. The status of PCS for the US. and Japan is truly in planning stages. Both the US IS-95 standard and the European GSM standard uses TDMA for RF multiple access. In many respects, there are similarities. Because GSM was planned and deployed earliest, it will be discussed in detail in the next two sections.

Digital cellular, in general, can provide both the voice service and the data service. Integrated service includes fax, paging, and other new digital features. The goal is to find the best compromise among efficient spectrum usage, low cost, and high service quality. Integrated service of digital cellular will surpass the features of the analog cellular systems in the following respect:

- frequency spectrum economy
- quality of voice and data
- cost of the mobile unit
- cost of the system infrastructure
- portability of handset
- new integrated services
- security

European GSM Cellular System:

GSM system architecture includes the Mobile Station (MS), the Base Station Subsystem (BSS), and the Network and Switching Subsystem (NSS). Each subsystem includes various elements as shown in Table IV. One breakthrough feature is to disassociate equipment ID from the subscriber ID. EIR is a database for equipment data management that allows the tracking of faulty or stolen equipment. HLR, VLR, and AUC are concerned with subscriber data management. HLR stores the mobile subscriber belonging to that area concerning its services (voice, fax, data, etc.). VLR controls the MS roaming in its area by temporarily storing visiting subscribers' information and locations and sending necessary information to the subscriber's HLR to route incoming calls. AUC is a strongly protected database which handles the authentication and encryption keys.

Mobile Station (MS)
Mobile Equipment (ME)
Subscriber Identity Module (SIM)
Base Station Subsystem (BSS)
Base Transceiver Station (BTS)
Base Station Controller
Network and Switching Subsystem (NSS)
Mobile Services Switching Center (MSC)
Home Location Register (HLR)
Visitor Location Register (VLR)
Authentication Center (AUC)
Equipment Identity Register (EIR)

Table IV: GSM Architecture Elements

	GSM 900, Phase 1
Uplink	890-915 MHz
Downlink	935-960 MHz
Channel Bandwidth	200 kHz
ARFCN Channel #	1-125
TDMA Maximum	8
MS Maximum Power Range	1-8 watts 24 km
MS Power Control Steps	0-15
Modulation	0.3 GMSK
Modulation Data Rate Bit Period Time Slot Period Frame Period	270.833 kbps 3.692 ms 576.9 ms 4.615 ms

Table V: GSM Air Interface

GSM adopts a TDMA multiple access solution with the digital channels multiplexed in groups of eight slots in Frequency Division Multiplexed (FDM) channels of 200 kHz each. Table V shows the frequency bands of the up/down links. A MS is allowed to transmit 1 to 8 watts. Each MS is under power control coordinated by the Base Station Subsystem (BSS). It uses digital signal of Gaussian Minimum shift Keying (GMSK) for frequency spectrum efficiency. Eight MS are transmitting in burst in time interleaved slots. Each time slot for a MS is shown in Figure 2 that consist of 0.577 MS. There are three tail bits followed by 57 information bits and a flag is used to indicate speech or data. There is a 26 bit mid amble for equalizer training. After that there is another burst of 1 + 57 bits followed by three tail bits and a guard space of 8.25 bits. This is a compromise between a low number of MS per carrier and long enough time between slots for monitoring and "handover".

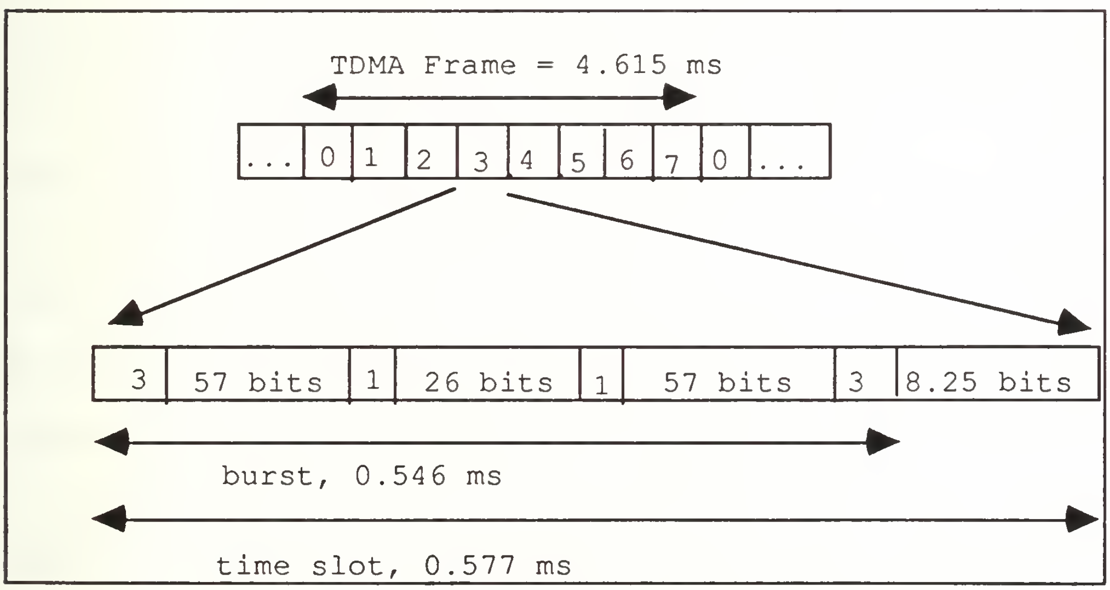

Figure 2: Time slot and frame of GSM.

Eight users on a frequency pair (one up link and one down link) must turn its transmitter on at the allowed time and have its transmitter off at other times to avoid interference. The amplitude envelope is also strictly controlled from slot to slot. GSM also allows for logical channels such as Slow Access Control Channel (SACCH) on top of physical Traffic Channels (TCH). MS subsequently, in time, receives traffic via down links after three time slots delay and transmit traffic to base stations via uplink. It then monitors the adjacent cell Broadcast Channel (BCH) power strength. This information is reported back to the Base Station (BS) every 30 seconds so that the BS can determine when to do a handoff.

To decrease multipath interference, some cells in a bad area are defined as a hopping cell. All mobile stations can perform channel hopping on demands. In a bad multipath area, each hand-off will be specified with three channels in hopping sequence defined in a Cell Allocation (CA) procedure. Every cycle of full duplex traffic including adjacent cell monitoring will be done according to the hopping sequence of the channels.

All GSM mobiles are able to control their output power in 2 dB steps. As the mobile moves around in the cell, its transmitting power needs to be adjusted. When it's close to the base station, it's power levels are set low to reduce the interference to other users. Due to varied distance ($\leq$ 35 km) between mobile and stations, the transmitter burst from an edge of the cell needs to be advanced so that it will arrive at the correct time with respect to other bursts from within the cell. In this way a collision of bursts from near or far mobiles can be avoided. The net voice coder bit rate is 3 kbps, which requires a Residual Excited Linear Predictor (RELP) with Long Term Prediction (LTP) codes. A half rate coder is under study which will be released in the future. Since GSM is inherently a digital system, it is capable of providing data transmissions as an integral part of the system. Interfaces to ISDN-type terminals and V or X series modems have been defined. Synchronous and asynchronous data transfer at 300 to 9600 baud rates are available.

GSM has a unprecedented arrangement for authentication and encryption mechanisim for a civilian telecommunication networks. Each subscriber will have Secret Key (Ki) and CCITT International Mobile Subscriber Identity (IMSI) stored in the SIM card. The Secret Key (Ki), which is not accessible outside SIM, is stored in the home mobile switching office Authentication Center (AUC). Protection of the IMSI is achieved by using an alias, Temporary Identity (TMSI) on the radio path when the user entered the local cell. When a subscriber first requests a call authentication, it is done by issuing a Random Number (RD) from the network to the MS. A Signed Response (SRES) and encryption key is produced through the security algorithm. Only SRES is returned over the air. If it is as anticipated by the network, both the MS and the network will use the same produced Communication Key (Kc) for signaling and data traffic. Ki and Kc will never be exposed on the air. Therefore, the Communication Key (Ki) is actually rolling from call to call, which enhances the security of communications further.

Notable GSM Features:

- ° Coordinated power control between base station and the mobiles.
- ° Maximum cell size (35 km) and limited radio power

(< 20 watts, usually 1-8 watts).

- Frequency hopping to mitigate multipath interference.
- Integrated services including voice, data, G3 fax, message
- handling services, videotex, and telefax.

Issues on GSM relevant to DoD:

Due to its early deployment in 1992, there are more experts and maintenance and operating equipment for GSM available on the market today. In the US., there are two digital cellular standards, IS-54 (TDMA) and IS-95 (CDMA) under development. For the same reason, the pacing of TDMA deployment similar to GSM is leading. From the DoD point of view, what are the issued that concern military application? The first issue is that GSM has base station power in the typical range of 1 to 8 watts (max. 30 watts). It is considered low power from a military application point of view. Military equipment is generally in the neighborhood of hundreds of watts. In terms of possible battle group application of cellular technology it requires controllable high power radios. The issue is the power controllable (power agile) radios which is rare and non-existing in military presently.

Another aspect is that for installed civilian cellular systems frequency and site planning are considerable tasks. Once it is measured in test and set up after planning, it becomes static. Only minor tuning is done afterwards in operation. If we are thinking of Navy battle group deployment scenario with a base station on a flag ship, both the base station and the mobiles are moving. In contrast, the base station is stationary in civilian cellular systems. Therefore, the method for protocol on power level adjustment and frequency hopping has to be modified. When a flag ship with a base station moves to different geological locations such as coastal locations, the frequency plans and hopping sequences have to be modified dynamically in time. This needs new development and research efforts before cellular technology can be deployed.

From the discussion in previous sections, it is shown that new DCS1800 of PCN (referred to as PCS in the US.) deployment in England is characterized by two aspects; high user capacity and low radiation power. This technology is more suitable for internal communication within a ship. The micro cell structure of PCN can correspond well to different compartments of ships. Connection infrastructures between micro cells can be provided through cable transmission.

The last issue is the security aspect of digital cellular. Subscriber ID will not be revealed often, and an alias is used. Traffic data and control signaling will be encrypted routinely. ECM measures such as "disclosure" will be more difficult. Clever low power jamming for "denial" is more appropriate than the raw power jamming, particularly, because of numerous cells that exist in metropolitan areas. It may be more feasible geographically to disperse large numbers of clever jammers in this situation.

Doctrine Transition From Terminal based Communication to Personal based Communication:

In the area of tactical telecommunications of DoD, there are some differences among the services. For Army, there are mounted soldiers versus dismounted soldiers. Mounted soldiers are usually riding in some kind of platform. Platform to platform is a kind of terminal based communications which are identified on the platform basis; a helicopter, a tank, or a floating vessel. Dismounted soldiers are organized at the platoon level. The smallest unit for telecommunication is the platoon unit. The Army has the need to extend the telecommunications to individual soldiers, which turns out to be a kind of personal based communication. There is a ARPA project on "soldier's radio" aimed at that goal [8].

For the Air Force, platform to platform or platform to base are also a kind of terminal to terminal communication. Parties are identified on the terminal basis. For an aircraft, personnel aboard are generally small in number. Therefore, there is no acute difference between personal based or platform based communication. In contrast, for the Navy, each surface or underwater platform involves hundreds of personnel. Traditional telecommunication is conducted from platform to platform on terminal basis. Intra-platform communication is organized in groups such as fly deck crews, fire control crews, and docking crews, etc. Consequently, intra-platform communication is strictly organized in "hierarchy". If a person to person communication is needed, the call has to go through all these hierarchical levels automatically or manually.

In previous discussions, wireless technology is aimed at person to person mobile telecommunication. It brings digital technology to individuals for all sorts of integrated services (voice, data, fax, video). Questions are raised regarding to possible tactical application of these technologies. The first issue for discussion is whether there is a need for person-to-person communication in Navy platforms or between platforms. In previous discussion, GSM subscribers are identified through a Smart ID Module (SIM card). The identification is on a person to person basis instead of a terminal basis. Basic GSM does not support peer to peer broadcast. On the other hand, Naval application such as fire control relies very much on peer to peer broadcasts. With a digital cellular system like GSM, peer to peer broadcasts are just another new feature which can be implemented into the Mobile Switch Center (MSC) very easily. Due to hierarchical communication within Navy platforms, there is a fundamental need of this kind of service. Even though wireless technology provide person to person communication, it can be modified to support hierarchical peer to peer communications like a conference call feature on a telephone system (PSTN).

New technology can afford us to support person to person communication. It will be beneficial for the Navy to exploit this new revenue, keeping in mind that a "logical hierarchical communication" can always be supported on physical person to person wireless technology. Presently, people are not fully aware of the benefits of person to person communication in this doctrine transition period.

Wireless Data Networks:

One area in this wireless technology development is the wireless data networks. It includes three categories, two-way paging, wireless Wide Area Networks (WAN), and wireless Local Area Networks (LAN). Traditionally, a paging system is a one-way communication system. When a code is broadcast, the identified pager is activated. There has been commercial effort to extend the one-way message service to a two-way message service. NWN, a two-way paging network, has set aside 50 kHz in the 930-931 MHz range for this kind of service. Due to inherent narrow bandwidth, the data rate in paging systems is typically low. Multiple users in a broadcast cell have to share the same carrier for service. Typically it can transmit only 50 to 100 characters for short messages. Noticeable providers are Skytel and EMBARC in this category. Due to the low functionality and limited operating coverage by metropolitan base stations, this kind of service may be of limited potential for military application.

The most successful wireless wide area data networks (WAN) are provided through two services. One is the ARDIS system, which is a joint venture between IBM and Motorola. The other is the RAM system, which is a joint venture of RAM Broadcast Corporation and Bell South Enterprises [9]. These services started in 1990. ARDIS is the largest carrier that holds FCC licenses for single channel operation in most of the 400 metropolitan areas. RAM operates in more than 100 cities that holds between 10 to 30 frequency channels from FCC. The summary of the characteristics and some technical features are shown in Table V.

	ARDIS	RAM	Cellular Plan II
Modulation	2-FSK	GMSK	GMSK
Error Correction	Convolution	Trellis Coding	Reed-Solomon
Multiple Access	DSMA	Slotted Aloha	Slided DSMA
Data Rate	4.8	8 kbps	19.2 kbps
Footprints (cities)	100	100	< 10
Protocol	RDLAP	MOBITEX Air Interface	CDPD
Roaming (Freq. Reuse)	No	Yes	Yes
Carrier Frequency	800 MHz	900 MHz	880 MHz
Usage Charge	packet	packet	packet/ time

*DSMA: Digital Sense Multiple Access

Table V: Wireless Data Networks

These are packet switching systems where messages are segmented into short pieces (packet) and transmitted through radios. There are some unique problems associated with wireless aspects of the network [10]. Unlike wired WAN, a radio channel in wireless WAN is noisy, interruptable, and susceptible to interference. Radio protocol at the link level is inherently very different from the wired line protocol such as SDLC or X.25. If typical wireline protocol were used over wireless links, retransmission causes delay, and may force the protocol to time out. ARDIS uses a RD-LAP protocol open to the public in 1991. RAM used MOBITEX network technology. The specification for air interface as well as the protocols are public and can be obtained from the MOBITEX Operators Association (MOA). ARDIS can provide a 4.8 kbps link with packets in the frame. This service is aimed at field service workers. RAM, on the other hand, provides a higher data rate at 8 kbps and additional nice features.

Another unique problem associated with wireless networks is the demand of "roaming" capability for mobile users. A user in the middle of transferring a sequence of packets can move from a cell of a base station to that of another base station. There should be no significant disruption of the transmission. For large file transfers the protocol should have recover mechanisms so that retransmission can start from the point of a break for efficiency reasons. Mobile users should be able to maintain a personal ID which is valid across all supported networks. The session of transmission is connectionless, that means a user is always affiliated with the network, but only connected at the instance when there is activity. ARDIS does not support user roaming, but RAM does allow user roaming. RAM also uses "trunking" to increase capacity by routing calls to the first available channel.

The security requirement for wireless data networks is just as critical as the other wireless technologies. Due to digital signaling and technology used, end to end encryption and decryption can be easily implemented. The Digital Encryption System (DES) technology from NTIS at very low cost (_ $20) is available on single electronic chips. Many vendors simply provide a socket on radio modem for the user to drop in encryption/decryption chips if it is desired. For this kind of service, usage is charged on a packet basis. Channels are shared among users, therefore the cost is low. For efficient spectrum usage, RAM uses Gaussian Minimum Shift Keying (GMSK) in the signal modulation. The error correction code is very capable, and the processing is demanding. Fortunately, digital signal processing can be done either on custom chips or DSP chips at low costs.

The third wireless Wide Area Network (WAN) under development is the Cellular Plan II [11]. This technology was developed by IBM. McCaw adopted this technology in its installed analog cellular system to provide data services such as fax and messages. This is a package switching technology which uses vacant channels of cellular systems. It requires additional hardware to be installed at the cell base station and Mobile Telephone Switching Offices (MTSO) [10]. This technology uses a Cellular Digital Packet Data (CDPD) protocol to overlay packet switching at 19.2 kbps on cellular to take advantage of idle air time of channels by interspersing data amongst voice conversations. The objective is to allow cellular operators to provide digital service to the public. The estimated cost of upgrading the existing analog cellular system is 400 to 500 million dollars. Deployment of this technology takes time. As was discussed previously, in the long range, analog cellular operators are moving towards digital cellular systems such as GSM, TDMA (IS-54), and CDMA (IS-45). Data services such as messages and fax are integrated into digital cellular systems already. There will be no additional cost to accommodate digital service. The main objective to go to digital cellular is to increase service capacity with the fixed frequency spectrum allocation, and decrease the per subscriber costs for better market penetration. In this transition period CDPD is considered as an interim approach to digital services. How will cellular providers react to these multiple approaches for digital services is hard to predict.

Currently, there are 13 million subscribers in the US. for cellular telephones. Cellular providers will have the advantage of an existing customer base to introduce digital services. Economic force and market initiation of CDPD is of great concerns to competitive providers such as ARDIS and RAM. Even though CDPD is a packet switching system, the packet traffic will be accommodated only if the voice channel is not busy. The average contention to use limited frequency systems is high at peak hours for CDPD. The acceptance and competition depends very much on the tarrifs difference between CDPD, ARDIS, and RAM. CDPD may be charged on both the number of packets and the connection time. ARDIS and RAM are charged based on the number of traffic packets. This way of tariffs turns out to be advantageous for ARDIS and RAM.

Wireless Local Area Networks (WLAN) is the most promising area of development for wireless date networks. Due to the opening up of unlicensed ISM bands for data (915 MHz, 2.4 GH, 5.76 GHz), private working groups are developing a IEEE 802.11 standard which targets a draft at the end of 1994 [12]. Even though the development is most immature, this standard will promote on-premises equipment and network deployment in the future. The most attractive feature is that ISM unlicensed bands can be shared by users without paying fees. Exactly for the same reason of shared band, severe interference may result in radio Bit Error Rate (BER) degradation or collapse. Standard and coordination of using this band are the keys to success. The first draft of IEEE 802.11 covers the 2.4 GHz band. Other frequency band standards will follow. The draft will cover two different radio physical interface and one infrared (IR) physical interface.

Even though the IEEE 802.11 draft is not available, the existing wireless LAN technology can be characterized in Table VI. The radio technology is generally designed among the trade-off between power consumption, data rate, and costs. For mobile application in LAN power consumption and costs are important design criteria. Two radio interfaces of very high interest are spread spectrum technologies. One involves the Direct Sequence (DS), which is similar to IS-95 CDMA in operation. The other is the Frequency Hopping (FH) that offers the best interference avoidance and natural diversity against multipath propagation effects. In general it costs less and provides longer range (800 to 1000 ft)

	Spread Spectrum Direct Sequence	Spread Spectrum Hopping Frequency	IR	Nonspread Spectrum (18 GHz)
Data Rate	250 K -- 5.7 Mbps	1-2 Mbps	5-10 Mbps	5-10 Mbps
Through-put	low to moderate	low to moderate	moderate	moderate to high
Indoor range (ft)	150-500	800-1000	150	150
Power con-sumption	medium	low	varies	high
Size/ weight	small/ low speed	small	small	big
Costs	moderate to high	moderate	low	highest

Table VI: Comparison of Wireless LAN Radio Interface

of operation than DS. The narrow band FH receiver allows non synchronous modulation and does not require system wide power control and coordination. Infrared interface potentially allows a high data rate but it is restricted to physical compartment with small operating range (150 ft). Costs of the IR device can be low. Another existing wireless LAN such as Motorola ALTAIR PLUS system is operating in Ku band (18 GHz). This system provides high data rates and costs a lot for installed operation. Operation of this system at Ku band requires licenses. Presently, IEEE 802.11 does not address standardization in the Ku band.

Issues in Wireless Data Networks relevant to DoD:

Wireless WAN such as ARDIS, RAM, and CDPD are targeted to mobile offices, field workers, retailing businesses, or warehouse inventory operations. The most potential growth belongs to wireless LAN where users can enjoy mobile benefits without paying carrier service fees. Anywhere in DoD operation that involve warehouse, inventory, and field work can benefit from the use of wireless WAN and wireless LAN.

Land Mobile Radio (LMR) Development:

The trend in the late 90s is to allocate more UHF frequency spectrum to emerging technology such as wireless communication and personal communication services (PCS). As a result, existing application such as land mobile radio will feel the crunch of frequency spectral band reduction. In order to accommodate the ever-expanding users for LMR, there is a big effort going on to shift the LMR technology to digital radio technology. The Association of Public Safety Communications Officials has a committee (APCO-25) that develops standards for the next generation of

Public Safety Wireless Communication Systems [14]. The committee has members from the state or local governments, public safety community, equipment manufacturers, and the federal government. The main objective is to adopt a Frequency Division Multiple Access (FDMA) system with a channel bandwidth of 12.5 kHz and a data bit rate of 9600 baud. This standard pointed out a spectrum migration path of channel bandwidth from 25 kHz to 12.5 kHz with QPSK-C modulation. This modulation allows a single receiver to handle both 12.5 kHz FM and very narrow band 6.25 kHz AM signals automatically to support migration.

The majority of LMRs are operating at 55 MHz (VHF), 450 MHz, and 815 MHz (UHF) range. For spectrum usage efficiency, the FCC initiated a re-farming spectrum below 512 MHz. 12.5 kHz bandwidth is an intermediate step to reduce bandwidth to 6.125 beyond the year 2000. NTIA, for the federal government, issued a directive calling for all new equipment to provide 12.5 kHz operation in 162--174 MHz by January 1995. The 406--420 MHz and 136--150 MHz refarming will be followed by January 1995. APCO-25 standards concentrate on the following interfaces:

- Common Air Interface (CAI)
- Subscriber data port interface
- Host and data network interface
- Telephone (PSTN) interconnect interface
- Inter-system interface
- Network management interface

The key portion is the Common Air Interface (CAI) that supports both digital voice and digital data services. The CAI can be summarized as follows:

modulation . . . . QPSK-C
channel access . . . . . FDMA
bandwidth . . . . 12.5 kHz
channel bit rate . . . . 9.6 kbps
Vocoder . . . . IMBE (Improved Multiband Excitation)
signaling format . . . . protocol adopted

The APCO-25 CAI adopted FDMA mainly to accommodate existing simplex, repeater, operating bases, and antenna. It requires minimum infrastructure change or modification. FDMA provides the wide range of flexibility and offers less spectrum efficiency as compared to the Time Division Multiple Access (TDMA) channel access method. The CAI supports both voice and data services and uses digital signaling.

The signaling is embedded in the super frame (360 msec) interleaved with the normal voice or data traffic. The signaling and its error correction occupies 25% of the data stream. It includes a unit ID, group ID, system ID, encryption sync, and other system information. The encryption sync contains sync, algorithm ID, the key ID, and parity. The data mode runs at 9.6 kbps in a 12.5 kHz channel. Therefore, approximately 7.2 kbps is available for user data such as fax image, and messages. There is considerable audio quality improvement. Background noise, static, and hiss of analog radio are gone. The perceived audio quality may have a "silent drop" characteristic, but digital radio provides a more consistent audio quality over a larger portion of coverage area.

Issues on LMR Development relevant to DoD:

From the Army point of view, APCO-25 standard is a significant development. The Army has the largest number of LMRs for tactical applications. Army radios such as Single Channel Ground and Airborne Radio System (SINCGARS) provide tactical linkage with additional anti-jamming and frequency hopping characteristics. Many issues like these are not addressed in the APCO-25 standard. The implication to DoD is related to the economics of the COTS available in the future for LMRs. They will be low cost because of both civilian and governmental usage. Due to its signaling flexibility and digital technology, it provides type 3 level (DES) security. There could be many situations where the Army would like to use this kind of COTS LMRs. In naval operations, shipyard logistics, base security, and mobile inventory all can benefit from using the future digital radio. In carriers flight deck control, ammo loading and maintenance, and docking operations it is possible to deploy future digital LMRs.

Mobile Satellite Services:

The idea of personal communication at anytime anywhere for PCS requires Mobile Satellite Service (MSS) as an important element. The military particularly are interested in the MSS development because military operations usually are away from metropolitan areas. Unfortunately, "civilian MSS" development is not as fast as cellular telephone or wireless data networks in terms of portability of low power satellite terminals and air connection costs. However, the trend is to build hand held portable terminals with connection pricing competition to the cellular phone. The objective of many MSS providers is to move MSS to the mass market. Once MSS service is available in consumer markets, DoD can benefit greatly to access these COTS facilities and services.

Discussion of MSS in this report will be limited to small and portable terminals. Large movable satellite services such as those available on ships and large land vehicles will not be covered in detail. The well known MSS provider is the INMARSAT organization. It started its "sea MSS" in 1982 mainly for maritime ship and rescue communications [15]. Its initial service is INMARSAT-A which costs $30,000 per terminal that is bulky with large C-band antenna on ships. Over many years of technology improvement, INMARSAT-A service will be replaced by INMARSAT-B, and the terminal can be in a suitcase form. In 1985 INMARSAT started "air MSS" which became popular as the aerophone in most of the US. domestic flights. In 1989 INMARSAT started "land MSS" which provides global coverage on land. This is in direct competition with other land mobile services.

This category of services relies on Geosynchronous Earth Orbiting Satellites (GEOS). The satellite is launched with an equatorial geosynchronous orbit at 35,000 KM (22,000 miles) away. Due to the extreme long distance to compensate radiation propagation loss, high gain antenna and high power systems are used. The ground terminal is usually radiating in hundreds of watts. The dish antenna needs to be pointed to the equatorial satellite for voice or high data rate service. As shown in

Table VII, the original INMARSAT-A and the replacement INMARSAT-B are basically this kind of service [16]. In the move to cut down total power and make terminals more portable, INMARSAT-C is designed. It uses omni-antenna with a loss of antenna gain which is only adequate enough to provide, store, and forward messages at a 600 bps rate. The size of the terminal is like a shoe box and can be accommodated in small craft at one third of the cost of INMARSAT-A. The idea of trading off bandwidth for small size and low power is generally in the same trend as Very Small Aperture Terminal (VSAT) development in the 80's. There is a future system, INMARSAT-M, planned to cover global MSS which, in addition to data, provides also low bandwidth (10 kHz/channel) voice. But, the terminal size is probably limited by the size of the antenna. Unless it can use omni (non-directional) in L-band, the antenna is the hurdle for achieving handheld portable terminals.

American Mobile Satellite Corporation (AMSC), formed by GM Hughes and AT&T, is aimed at a new generation of GEOS MSS [18]. It uses advanced phased-array multiple-beam antenna and space borne computers which provide four regional cells in North America and one regional cells in Central America. The system provides voice, data, and G-3 fax services on 7.5 kHz RF channels. Frequency reuse is designed for mass market subscribers. Omni L-band whip antenna

	Inmarsat - A	Inmarsat - B	Inmarsat - M	Inmarsat - C	AMSC-MSAT
Modula -tor	analog FM	digital offset QPSK	offset QPSK	digital BPSK	digital pi/4 QPSK
Service s	voice 9.5-56/64 kbps	voice coding 16 kbps	voice 4.2 kbps	store & forward 600 bps msg.	voice 4.2 kbps data G-3 fax
Gate-way	DSTN, DSDN Telex	PSTN, PSDN Telex		X.25, PSTN email	
Size	bulky	suitcase	suitcase	shoe box	lunchbox
Symbol Rate	N/A	21 kbps	6.4 kbps	1200 bps	6.4 kbps
Channel BW	50 kHz	10 Khz	10 kHz	5 kHz	7.5 kHz
Anten-na	C-band large	C-band large	C-band light-wgt.	C-band omni	L-band small
Avail. year	1976	1993	future	1990	future
Satellite Beams	Single	Single	Single	Single	Multiple
Cellular Handoff	No	No	No	No	Yes

Table VII: Summary of Some GEO MSS

will be used in a lunch box terminal (still not pocket size yet!), which is suitable as a mobile vehicle terminal. With all the engineering twigging, the terminal still needs to emit one watt and above of power. This is probably the dominating feature that distinguishes itself from Low Earth Orbiting Satellite (LEOs), which require terminals only a fraction of a watt's power. In order to face the competition of land based mobile services, AMSC-MSAT will provide "roaming" and interoperability with terrestrial cellular systems following TIA standard IS-41. The terminal they are going to market will be dual mode either operating through MSAT or through terrestrial cellular systems. "Hand-off" can be done automatically based on the customer's preference. It will provide the service at $1.45/minute anywhere in North and Central America. As you will see, there will be a market shakeup once the service becomes available. How advanced space technology can stand and how customers will accept this "anywhere" service will determine the success of the ASMC-MSAT.

In contrast to the GEOS technology, recently a large number of efforts are centered around LEOS technology [17]. MSS bandwidth in L, C, Ku, S bands are limited and regulated by the World Administration Radio Conference (WARC). Even with multiple-beam global cells (foot prints) provided in AMSC-MSAT, still not enough bandwidth is available for the world mass market. In order to increase frequency reuse, the approach is to decrease the global cell size and have many small global cells covering the footprints on earth. LEOS is exactly this kind of system. There are two LEOS systems. One is the big LEOS, and the other is the small LEOS. Big or small is all related to the number of satellites orbiting in constellation. The LEOS is usually at an altitude of 400 to 8000 km. They can be in polar, inclined, elliptical, or circular orbit. Elliptical orbits can also be optimized to have low altitude in the North American continent.

Because of their proximity to the earth terminal, propagation loss is much less and the terminal radiates in 100 of milliwatts using nondirectional omni antenna. This quantum reduction in radiated power compared to GEOS is the key feature of the proponents of LEOS technology in the 1990s. In the early 50s and 60s a large number of pioneer satellites are LEOS. Tracking of LEOS and signal storage are the main problems. Toward the end of the twentieth century, digital technology will allow inexpensive signal storage. This really rejuvenates the LEOS to a new horizon. If enough LEOS's are flying overhead, tracking antenna can be avoided by using omni whips. A large number of LEOS can move in line of sight (LOS) over the horizon. Each satellite has a small cell whose footprint is moving on earth. Real time traffic such as voice can be "hand-off" to the neighboring satellite just in the same way as a cellular base station "hand-off" ongoing calls. In this situation, the base station is moving, and the mobile terminal of a user may also be moving. Roaming and interworking between terrestrial cellular systems and telephone (PSTN) systems were demonstrated successfully in the past. Many believers think LEOS can enjoy the same success in the future.

The most notable big LEOS is the IRIDIUM promoted by Motorola. So far $270 M was committed to the project. Motorola has signed a $700 M contract with Lockheed to build the main portion of the satellite. IRIDIUM has 66 satellites in the constellation as shown in Table VIII. This system will provide both voice and data service in dual-mode with regular cellular systems, just like the AMSC-MSAT. Subscriber links are in L-band with pocket sized terminals. Satellite technology is quite advanced with each satellite generating 48 spot beams. "Hand-off" of on-going calls can be done from the satellite to neighboring satellites through interlinks in Ka-band. Phased array antenna and advanced switching computers have to be space-borne. This system is truly global and needs 20 gateway ground stations. Because of the large constellation, maintenance of satellite operation and launching will be going on most of the time in a year.

Therefore, the estimated operation cost is very high, in the $250-850 M range. Critics of IRIDIUM do not like the high annual cost and the advanced technology because they will translate to high connection cost to the users. Estimated user cost of IRIDIUM is about $3.00 per minute. For the consumer market with other alternatives MSS, this tends to be high. If this system is successful, high quality global voice and data services will be provided.

	Big LEOS IRIDIUM	Small LEOS ORBCOMM
Constellation	66, 6 orbital planes	26
Orbit	780 km	785 km
Multiple Beam	48 spot beam/ satellite	none
Intersatellite Link	between space borne computers (Ka-band)	none
Voice	dual mode, satelite and terrestrial at 4.8 kbps	none
Data	2.4 kbps	2.4 kbps/up 4.8 kbps/down
Modulation	QPSK (FDMA/TDMA)	DPSK
Gateway to PSTN	20	4/U.S.
Subscriber Link	L-band	VHF
Target Year	1998-2000	1995
Annual Fixed Costs	$250-850 M	$35 M

Table VIII: Summary of Some LEOS MSS

Like the approach taken by INMARSAT-C, the small LEOS tradeoff data rate for small constellations and low operation costs. ORBCOMM is the notable small LEOS providing only the store and forward data. Subscriber links of ORBCOMM system are in VHF range. Only four ground stations are required for message service in the CONUS. The ORBCOMM satellite is lightweight and needs only space-borne data storage capacity. The annual operating cost is low in comparison to a big LEOS system. Targeted service will be open in 1995 in full scale. Messaging, tracking, data acquisition, and emergency rescue are some of the possible applications.

Issues on Mobile Satellite Service (MSS) relevant to DoD:

The civilian development is going toward minimizing the subscriber terminal. With low power operation it is possible to construct portable pocket size terminals. DoD and other foreign military are already heavy customers of civilian MSS such as INMARSAT-A, -B, and -C. The advanced GEOS such as AMSC-MSAT and large and small LEOS in the development stage will benefit DoD in the future. From the experience of VSAT, the lesson learned is that VSAT is successful not because of DoD's demands but because of the volumes of civilian deployment. If MSS future development can penetrate large civilian markets, DoD can benefit by deploying these services. Certainly, unique DoD requirements such as Multiple Priority Preempt Level (MPPL) security, Anti jam (AJ), and Low Probability of Interference and Detect (LPI/LPD) are absent in commercial MSS. But, convention wisdom is that large numbers of DoD applications probably can tolerate this kind of low cost services.

There is skepticism with respect to the prospect of success for systems like AMSC-MSAT, IRIDIUM, and ORBCOMM. Only market shake-out will determine the winner. DoD cannot influence the shake-out, but should plan for possible use of these kinds of services in the future.

DOD Wireless Requirement:

The Most difficult part in this study is to survey on the DOD wireless requirements because there are too many entities and activities directly or indirectly related to DOD. The best information is a result of study on Commercial Satellite Communication Initiative (CSCI) program conducted for DISA by Loral, Hughes, and COMSAT. However, the study was concentrated on Satellite Services [19]. Because radio links are involved in services, the method of analysis in the study can be extended to wireless services in general.

There are seven mission areas: strategic/nuclear, theater/tactical, special operations, intelligence, defense communication system (DCS)/NCS, space support, and non DOD. For each of these areas the following criteria are documented; coverage and connectivity, service capability, survival-anti jam (AJ) and low probability of interference and detect (LPI/LPD), allowable interrupt outage, flexibility for interoperation , reconfiguration, and deployment, terminals, and control. Each mission may have different degree of requirements on capacity, AJ and LPI/LPD, and flexibility, etc.. What was involved is to examine an Integrated Satellite Communication Data Base (ISDB) that was collected in actual operations. Details of the requirements are classified.

The issue involved in this report is what are the requirements of wireless technology for DOD. This will only be accurate if future wireless demands for DOD can be predicted. Since prediction is difficult., the analysis method mentioned above can be useful to reveal the possible requirements on future wireless technology.

There is a Federal Wireless Policy Council (FWPC) in works. It was proposed to have five standing committees: policy, standards, security, acquisition, and federal wireless user's forum. The standard committee will coordinate effort on government wireless requirements. DOD will have on vote conducted by J-6. NTIA is chairing the FWPC. Several user's forum has been conducted last year. How successful can this council relays DOD wireless needs to industry remains to be seen.

Conclusion:

Telecommunication industry and computer industry seems mature enough and are ready to lunch the effort to build the National Information Infrastructure (NII). Wireless technology is and essential element to provide secure services to individual any time and any place. DOD traditionally invest a lot in wireless technology and radio communication. How can DOD benefit from this future development is the key issue of this report. If DOD adheres to the C4I for the worriers concept, the "last mile problem using wireless technology is an important link in the total solution. The future development for wireless technology were divided into PCS, wireless data, digital LMR, and mobile satellite service areas. Possible DOD applications using theses technologies were discussed.

The key concepts reveal in the future wireless technology are related to integrated and intelligent networking. To increase total capacity for mass market such as PCS, "power control" is and essential ingredient in the scheme. It is not difficult technically to overlay novel services on top of digital networks. Most wireless technology can incorporate encryption/decryption and security comfortably. For each known DOD application (communication loads) it's possible to analyze the requirement in loads versus requirements of service provided form carriers. With some orientation of traditional DOD concept and doctrine benefits of using commercial technology (COTS) can be great.

Acronyms:

AMPS:	Advanced Mobile Phone Services, used in North America
BSS:	Base Station Subsystem (GSM)
BTA:	Base Trading Area
CDMA:	(IS-95) Code Division Multiple Access
CDPD:	Cellular Digital Packet Data
COTS:	Commercial Off the Shelf
DS:	Direct Sequence
DSP:	Digital Signal Processing
FCC:	Federal Communications Commission
FH:	Frequency Hopping
FPLMTS:	Future Public Land Mobile Telecommunication System
GEOS:	Geosynchronous Earth Orbiting Satellite
GMSK:	Gaussian Minimum Shift Keying
GSM:	Global System for Mobiles, European standard of mobile service in the 900 MHz spectrum
INFORUM:	Wireless Information Network Forum
IR:	Infrared
LAN:	Local Area Networks
LEOS:	Low Earth Earth Orbiting Satellite
LMR:	Land Mobile Radio
MOA:	Mobitex Operators Association

MSC:	Mobile Switching Control (GSM)
MSS:	Mobile Satellite Services
MTA:	Major Trading Area
MTSO:	Mobile Telephone Switching Offices (AMPS)
NSS:	Network Switching Subsystem (GSM)
NTIA:	National Telecommunications and Information Administration, the government counterpart of the Federal Communications Commission
PC:	Personal Computer
PCS:	Personal Communication Systems
PSDN:	Public System of Data Networks
PSTN:	Public System of Telephone Networks
SATCOM:	Satellite Communication
SIM:	Subscriber ID Module (GSM)
TDMA:	(IS-54) Time Division Multiple Access
VOCODER:	Voice Coder
WAN:	Wide Area Networks
WLAN:	Wireless Local Area Networks
WPBX:	Wireless Private Branch Exchange
WWAN:	Wireless Wide Area Networks

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